DIFFERENCES BETWEEN COAL AND HYDROCARBONS (PETROLEUM)

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ABSTRACT:

To differentiate between Coal and Hydrocarbons such as Petroleum with respect to their mere physical properties is not a difficult task even to the layman. Since Hydrocarbons are not limited to Petroleum only, difficulty arise to some people whether coal can also be classified as hydrocarbon or not. Coal is sometimes wrongly classified as hydrocarbons. However, both Coal and Hydrocarbons (liquid hydrocarbon and natural gas) are of great economic importance as fusel fuels. Coal for example is the largest source of energy for the generation of electricity worldwide, as well as one of the largest worldwide anthropogenic sources of carbon dioxide releases. Even though, they are both fossil fuels, and shared many similarities and economic importance in common, yet they differs significantly not only in their physical properties but also in their Genesis, Formation, mode of deposition, Chemistry and Geophysical Properties. The purpose of this paper, is to briefly highlight these differences.

KEYWORDS: coal, petroleum, hydrocarbons, natural gas, kerogen, peat, lignite, coal formation, hydrocarbons formation, differences between coal and hydrocarbons, fossil fuels.

1. DEFINITION:

Both Coal and Hydrocarbons are organic compounds, however, they differ significantly. In organic chemistry, a hydrocarbon is an organic compound consisting entirely of hydrogen and carbon.[1] Hydrocarbons are the principal constituents of petroleum and natural gas. Extracted hydrocarbons in a liquid form are referred to as crude oil or liquid petroleum (literally "rock oil"), whereas hydrocarbons in a gaseous form are referred to as natural gas, and the solid form of Hydrocarbons are called Asphalt (also known as bitumen).[2]

Petroleum and natural gas are found in the Earth's subsurface with the tools of petroleum geology and are a significant source of fuel and raw materials for the production of organic chemicals. There are referred to as **fossil fuels.**[3]

Coal on the other hand, is a **solid combustible carbon-rich material** that is usually brown or black and most often occurs in stratified sedimentary deposits.[4] Thus, it is simply a black or brownish-black sedimentary rock usually occurring in rock strata in layers or veins called **coal beds** or **coal seams** ranging in thickness from just millimetres to many meters. Typical thickness of coal beds is **half a meter to a few meters**

Like those economically important hydrocarbons (Crude oil and natural gas), coal is also one of the most important primary **fossil fuels** [5]. However, from the definition of both Coal and Hydrocarbons given above, we can deduce at least one important difference between these organic materials based on their composition and Chemistry. In general, coal can be considered **a hydrogen-deficient hydrocarbon** with a hydrogen-to-carbon ratio **near 0.8**, as compared with a liquid hydrocarbons **ratio near 2** and a gaseous hydrocarbons **ratio near 4** (for gasoline). For this reason, any process used to convert coal to alternative fuels must add hydrogen (either directly or in the form of water).

2. DIFFERENCE IN THEIR CHEMISTRY:

Unlike Hydrocarbons, which contains Carbon-Hydrogen atoms linked together by a covalent bond, Coal is composed primarily of carbon, contain appreciable percentages of other constituents elements as well, chiefly **hydrogen, sulfur, oxygen, and nitrogen** (only a couple of percent; and does not vary significantly. Probably from the organic matter itself, not from entrapped air).

Therefore, Coal and Hydrocarbons differs significantly in their Chemistry; Hydrocarbons (contains C and Hydrogen Only) while Coal (contains other variables elements). [6]

Let us consider briefly the chemical difference of Coal and Hydrocarbons (Crude oil and Natural gas)

2.1 Natural gas is a mixture of lightweight alkanes. A typical sample of natural gas when it is collected at its source contains 80% methane (CH_4), 7% ethane (C_2H_6), 6% propane (C_3H_8), 4% butane and isobutane (C_4H_{10}), and 3% pentanes (C_5H_{12}).

2.2 Crude oil is a complex mixture that is between 50 and 95% hydrocarbon by weight. The first step in refining crude oil involves separating the oil into different hydrocarbon fractions by distillation. A typical set of **petroleum fractions** is given in the table below. Since there are a number of factors that influence the boiling point of a hydrocarbon, these petroleum fractions are complex mixtures. More than 500 different hydrocarbons have been identified in the gasoline fraction, for example.

Fraction	Boiling Range (°C)	Number of Carbon Atoms
natural gas	< 20	C_1 to C_4
petroleum ether	20 – 60	C_5 to C_6
gasoline	40 – 200	C_5 to C_{12}, but mostly C_6 to C_8
kerosene	150 – 260	mostly C_{12} to C_{13}
fuel oils	> 260	C_{14} and higher
lubricants	> 400	C_{20} and above
asphalt or coke	Residue	polycyclic

2.3 Coal is a complex substance that can be found in many forms. Coal is divided into four classes, with each class having different percentage of Carbon by weight:[7]

I) Anthracite (hard coal): Anthracite coal is a dense, hard rock with a jet-black colour and a metallic lustre. It contains between **86% and 98% carbon by weight**, and it burns slowly, with a pale blue flame and very little smoke.

II) lignite (brown coal): Lignite coal, or brown coal, is a very soft coal that contains up to **70% water by weight.**

III) Bituminous (soft coal): Bituminous coal, or soft coal, contains between **69% and 86% carbon by weight** and is the most abundant form of coal.

IV) Sub-bituminous: Sub-bituminous coal contains less carbon and more water than

Bituminous coal, and is therefore a less efficient source of heat.

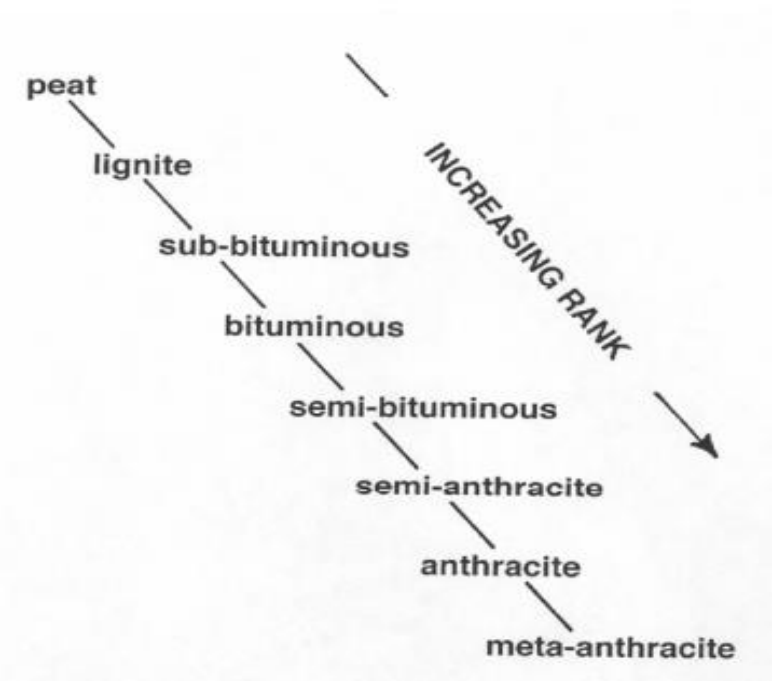


Figure 1: The Spectrum of Coal rank Material even less diagenetized than lignite is called peat

Elemental analysis gives empirical formulas such as **$C_{137}H_{97}O_9NS$ for bituminous coal** and **$C_{240}H_{90}O_4NS$ for high-grade anthracite.**

Apart from variable quantities of other elements such N, S and O, Coal also contains appreciable percentages of other constituents substances such as: **water** (varies with rank from a few percent to as much as 90%), variable percentages of **gases** (CO_2, O_2, N_2, CH_4), and **ash** which is the solid residue upon combustion: (sand, silt, and clay) in variable proportions, either carbonate or siliciclastic (mostly the latter). From fractions of a percent in the cleanest coal to such large values that the rock should be called a **carbonaceous shale** or **a carbonaceous sandstone** rather than coal. **Very impure coal is called bone coal.**[8]

Let us consider the rank of coal in relation to a carbon-hydrogen-oxygen composition. The figure below shows one segment of a composition triangle whose end members are percent of carbon, hydrogen, and oxygen. Only the area nearest the carbon corner is occupied by rocks we would call **coal**.

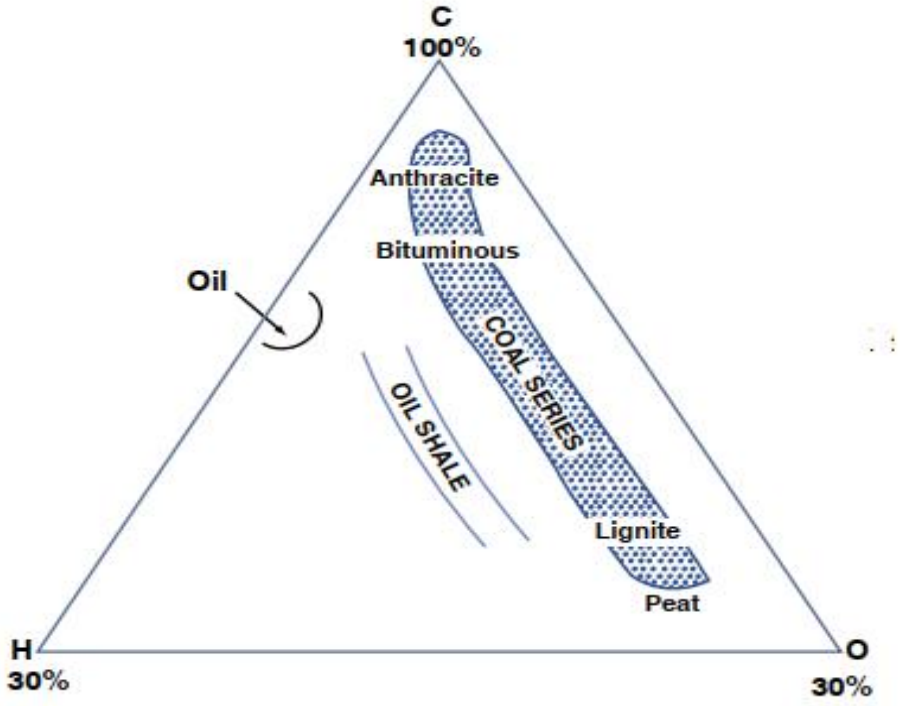
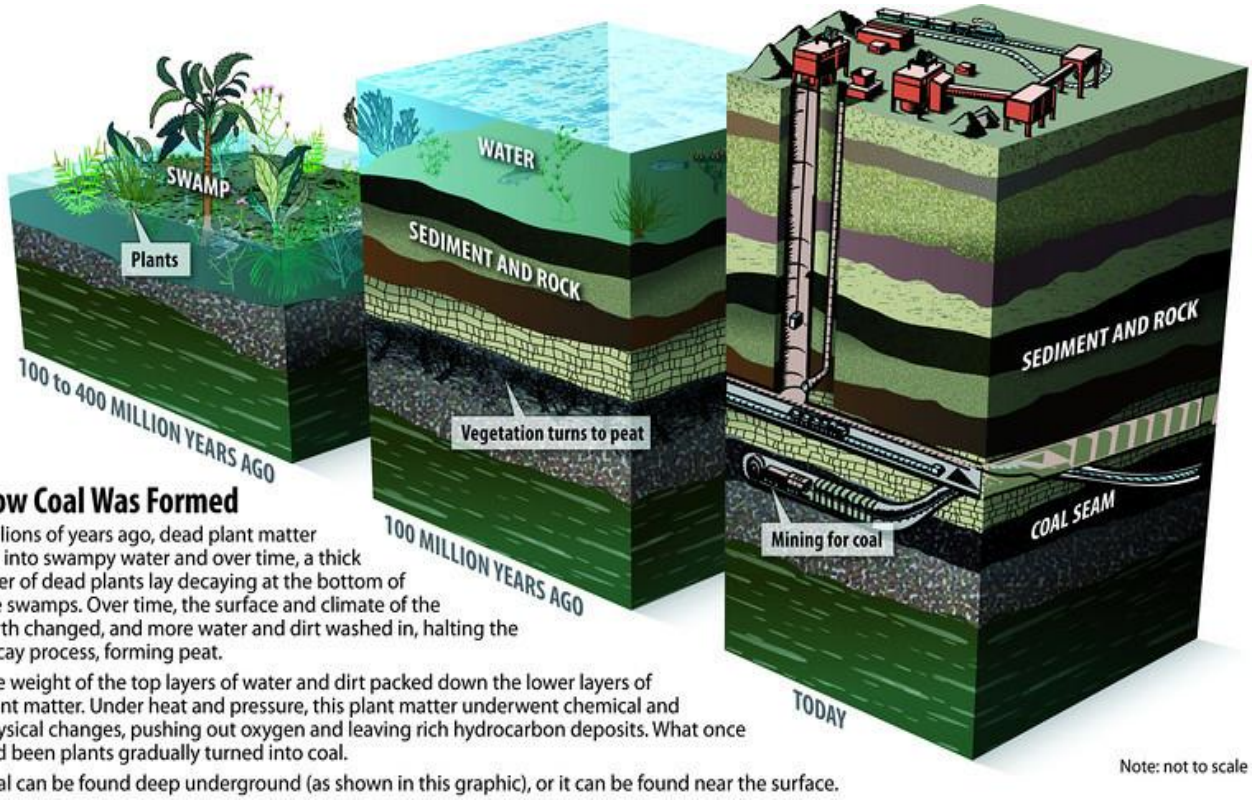


Figure 1: **The rank of coal in relation to a carbon-hydrogen-oxygen composition Triangle. From Massachusetts Institute of Technology OpenCourseWare (MIT OCW).**

We can see that the ***increase in rank is associated with a progressive decrease in the percentages of hydrogen and oxygen***, presumably owing to driving off of the volatile constituent water.

3. DIFFERENCES IN THE FORMATION OF COAL & HYDROCARBONS:

When discussing the formation and occurrence of Hydrocarbons such as petroleum , it is necessary to include a brief review on relevant aspects of coal formation. Both petroleum and coal originate predominantly from organisms of the plant kingdom and both are subjected to the same geological processes of bacterial action, burial, compaction, and geothermal heating that constitute diagenesis and catagenesis. There are, however, also some essential differences between the modes of ***coal and petroleum formation. Basically, these differences centre around the fact that coal is found at its site of deposition as a solid and relatively pure massive organic substance,*** whereas ***petroleum is fluid and migrates readily from its place of origin into porous reservoir rocks***. Reactive Kerogen is the main precursor material of petroleum compounds. It is finely dispersed and intimately mixed with the mineral matrix in petroleum source beds. Most coals are remnants of terrestrial higher plants, whereas the reactive kerogen of petroleum source beds is generally dominated by aquatic lower plants and bacteria. Most acknowledged petroleum source beds were deposited in marine environments and most coals formed under non-marine or Paralic conditions.



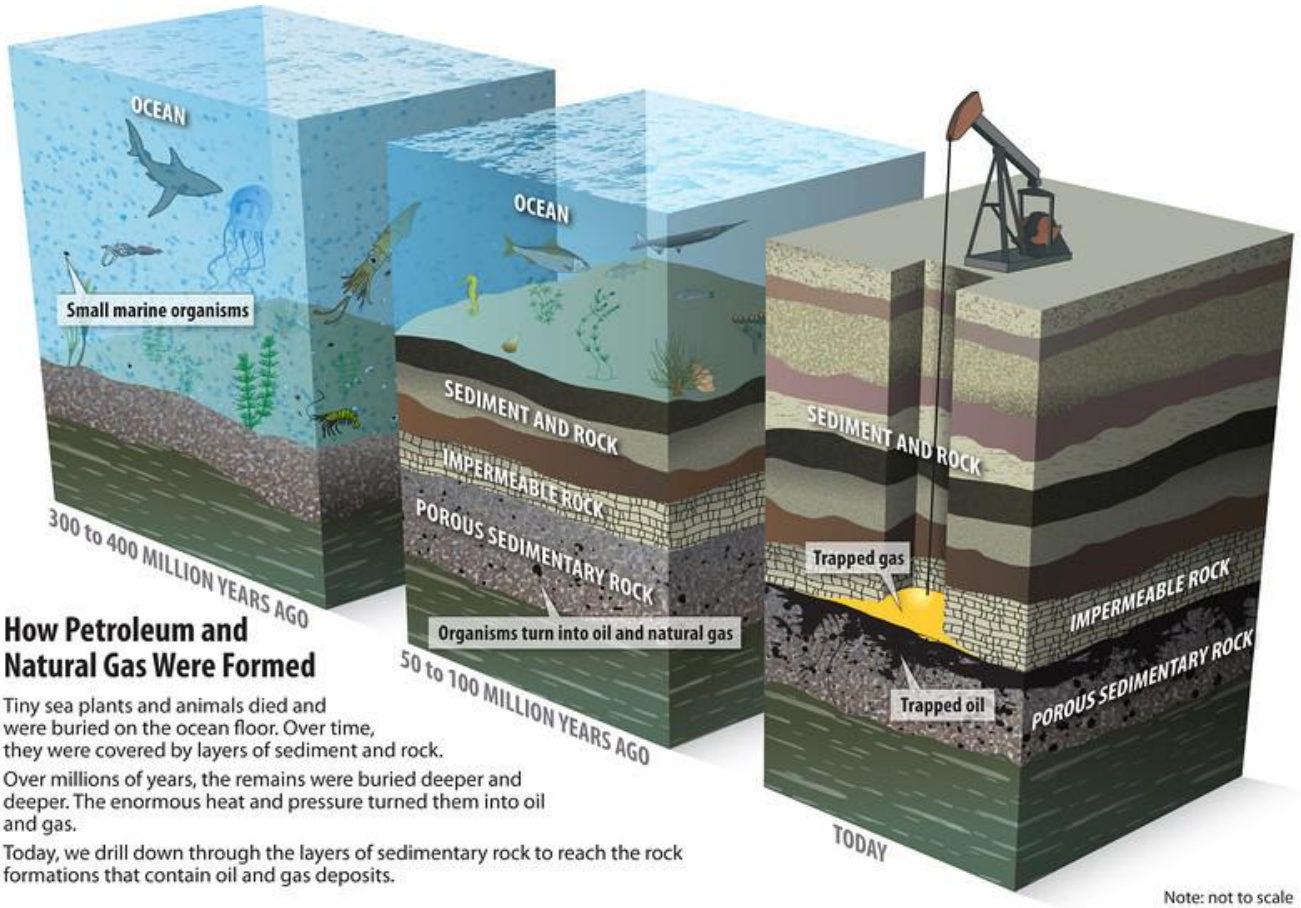
How Coal Was Formed

Millions of years ago, dead plant matter fell into swampy water and over time, a thick layer of dead plants lay decaying at the bottom of the swamps. Over time, the surface and climate of the Earth changed, and more water and dirt washed in, halting the decay process, forming peat.

The weight of the top layers of water and dirt packed down the lower layers of plant matter. Under heat and pressure, this plant matter underwent chemical and physical changes, pushing out oxygen and leaving rich hydrocarbon deposits. What once had been plants gradually turned into coal.

Coal can be found deep underground (as shown in this graphic), or it can be found near the surface.

Note: not to scale



How Petroleum and Natural Gas Were Formed

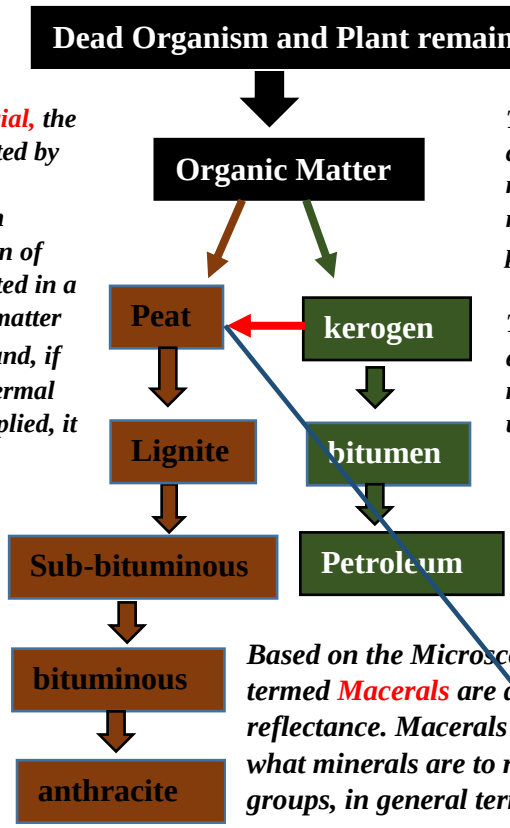
Tiny sea plants and animals died and were buried on the ocean floor. Over time, they were covered by layers of sediment and rock.

Over millions of years, the remains were buried deeper and deeper. The enormous heat and pressure turned them into oil and gas.

Today, we drill down through the layers of sedimentary rock to reach the rock formations that contain oil and gas deposits.

Note: not to scale

The following flowchart is an attempt to describe the stages of Coal and Hydrocarbons formation from Peat and Kerogen respectively.



In the case of terrestrial burial, the organic sediment is dominated by cellulose and lignin and the fraction of minerals is much smaller. Here, decomposition of the organic matter is restricted in a different way. The organic matter is condensed to form peat and, if enough temperature (geothermal energy) and Pressure is supplied, it will condense and undergo cataaenesis to form coal.

Higher temperatures and pressures, in general, lead to higher ranks of coal, from Lignite to Anthracite.

The deposited organic aquatic sediments (proteins, lipids, carbohydrates) are very saturated with water and rich in minerals. Through chemical reaction, compaction, and microbial action during burial, water is forced out and proteins and carbohydrates break down to form ''kerogen".

Therefore, Kerogen is formed from Organic matter, as the end product of diagenetic process, after it undergone microbial degradation, polymerization and condensation under mild conditions of temperature and pressure.

Bitumen becomes Petroleum after Migration from the source rock to reservoir rock.

Based on the Microscopic analyses of organic remains, kerogen particles termed Macerals are described on the basis of their morphology, color and reflectance. Macerals are essentially organic minerals, they are to kerogen what minerals are to rock. These macerals are divided into three main groups, in general term,

are oil prone (liptinite group derived primarily from algal remains and exinites group derived from leaf, spores, pollen, algae, plant waxes, resins, fats, and oils), gas prone (vitrinite group) and those which has no potential (inertinite group).

Liptinite, Exinites, and Vitrinite group are hydrocarbon prone because they have high H/C ratio due to their Origin. While inertinite group consists of carbonized remains formed by rapid oxidation under aerobic conditions (peat-producing environments), Low H/C and high O/C ratios. Therefore, they form peat which eventually turns to Lignite coal over time.

The quality and quantity of the Peat or Kerogen depend on the following:

1. The type of the Organic matter deposited.

If the Organic matter originated from higher terrestrial plant, Peat will be produce. This is because Higher terrestrial plants have very high percentage of Cellulose (30-50%) and Lignin (15-25%) which contain high percentage of C, and very low percentage of hydrocarbon prone organic compounds, Protein (3%). This is why coal have very low H/C ratio whereas hydrocarbons have high H/C ratio.

But in the case of Organic matter originated from phytoplankton (50% Protein, 40% Carbohydrates, and 5-25% lipids), the Organic matter will be very reach in lipids, and therefore, hydrocarbon prone or good producer of high quality kerogen.

This is why of the four types of kerogen, Type I. II are good hydrocarbons producers, whereas type III which is very similar to Peat usually produce Coal and gas, types III also produce gas.

2. The concentration and nature of the Oxidizing agent,
3. The Sediment accumulation rate, and
4. The environmental factors (rate of burial, water table and climate) driven the geological processes.

4. THEIR GENESIS OR ORIGIN:

Coal (carbonized plant matter) is formed from Marsh Swampy - Plant based Environment while Petroleum is formed from Organisms (mainly Marine Environment in origin).

5. STERANES:

Hydrocarbons are mainly from Organic matter dominated by C27 sterols while Organic matter that yield Peat are mainly from C29 sterols.

6. THEIR MODE OF DEPOSITION:

Coal formations tend to deposit laterally. (Also a reason why they are used as a marker for Well to well correlation). While this may not be necessary for Hydrocarbons Formations.

7. DIFFERENCE IN THEIR PHYSICAL PROPERTIES:

1) Permeability (measure of fluid flow through permeable/porous media) is a physical property that differs significantly between coal and hydrocarbons.

For instance, Coal Permeability often dictated by Random Cleat system (fracture system) as well as Matrix system and are heavily influenced by rate of production. It can even Shrink. Whereas most Petroleum Formations have Matrix system and not as heavily influenced by production rate as Coal. This is main reason why Simulating Coal formation is difficult.

2) Rock Strength: Coal is extremely friable. Meaning apply a 10–20 psi and it will break. Think of a Biscuit. Whereas hydrocarbons aren't as weak as Coal. Sometimes they even require Hydraulic fracturing just to break.

3) State of Matter: Coal is Solid, while hydrocarbons such as Petroleum are fluids.

8. COMBUSTION CHEMISTRY:

The balanced **chemical equation**[9] for the complete combustion of a general hydrocarbon fuel C_xH_Y is given by $C_xH_Y + (x + \frac{Y}{4})\, O_2 \longrightarrow xCO_2 + \frac{Y}{2} H_2O$ while coal has no general chemical equation for its combustion.

9. CATEGORIES OF NATURAL SUBSTANCES:

Natural products can be classified into three categories: **micromolecules** with uniform molecular structures; **large molecules (Macromolecules)** with uniform molecular structures; and **mixtures of micromolecules and polymers** with various molecular structures. **Coal** belongs to the last category and contains large molecules with various molecular Structures. While **Hydrocarbons** are macromolecules

CONCLUSION

As we have seen above, Coal and Hydrocarbons (such as Petroleum and Natural gas) differs in numerous ways, such as their Genesis, Formation, manner of deposition, Geophysical and Chemical properties. Both originated from Organic matter, which give rise to Reactive Kerogen or Peat and subsequently (after undergoing geological processes over long period of time) produce hydrocarbons or Coal respectively. Coal is a particular variety of kerogen, that forms from remains of superior plants (trees and ferns). It is a kerogen of terrestrial plant origin that has the characteristic of being dominant in the sediment (swamp) instead of being a very a small fraction of it. The first stage of the sedimentation process leads to peat. During burial under favourable conditions, lignite is produced from the Peat, then coal, then anthracite, which is almost pure carbon, with almost no hydrogen. Just like other kerogens, coal produces oil and gas during its burial under favourable conditions, though in lesser quantities regarding oil. But as Kerogen is not hydrocarbon, so also Coal.

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